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High Field Dipoles for GTeV Experiment at the Tevatron

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Abstract – This note discusses the possibilities of creating the necessary space for the installation of roman pots in the Tevatron using stronger dipole magnets with the nominal field of 6.7-9 T. Magnet design concepts and technologies are discussed. The draft program schedule and cost are also presented.

Introduction

For the proposed GTeV experiment at the Tevatron some regular arc dipole magnets have to be replaced by new stronger and shorter dipoles in order to provide space for roman pots. Recently a similar problem of creation of space in the Tevatron lattice for installation of additional electrostatic beam separators has been studied. The results of this analysis are summarized in [1]. It was found that the most optimal scenario driven by the task timescale and cost is when 3 present dipoles in a half-cell are replaced by 2 new magnets providing 3-m long space for the separators. Based on the time scale of this project the recommended magnet design was 2-layer dipole based on NbTi superconductor with the nominal field of 5.5 T and magnetic length 8 m.

Due to a larger space required for the roman pots (>4 m) and different project schedule this analysis has to be revised. This note discusses the possibilities of creating the necessary space using stronger dipole magnets with the nominal field of 6.7-9 T. Magnet design concepts and technologies are discussed. The draft program schedule and cost are also presented.

Lattice modifications and magnet parameters

Standard Tevatron half-cell consists of four dipoles and one quadrupole. Main dipole magnet parameters are:

- Nominal magnetic field at 1 TeV beam energy B_{nom}=4.4235 T
- Dipole magnetic length L_{mag}=6.1214 m
- Magnet end length L_{end} =0.1397 m

The 4-m long (or larger) space for the roman pots could be created using several scenarios (see Fig.1):

– 4 present dipoles are replaced by 2 new ones (Fig 1a)
– 3 present dipoles are replaced by 2 new ones (Fig 1b)
– 2 present dipoles are replaced by 1 or 2 new ones (Fig 1c and 1d)

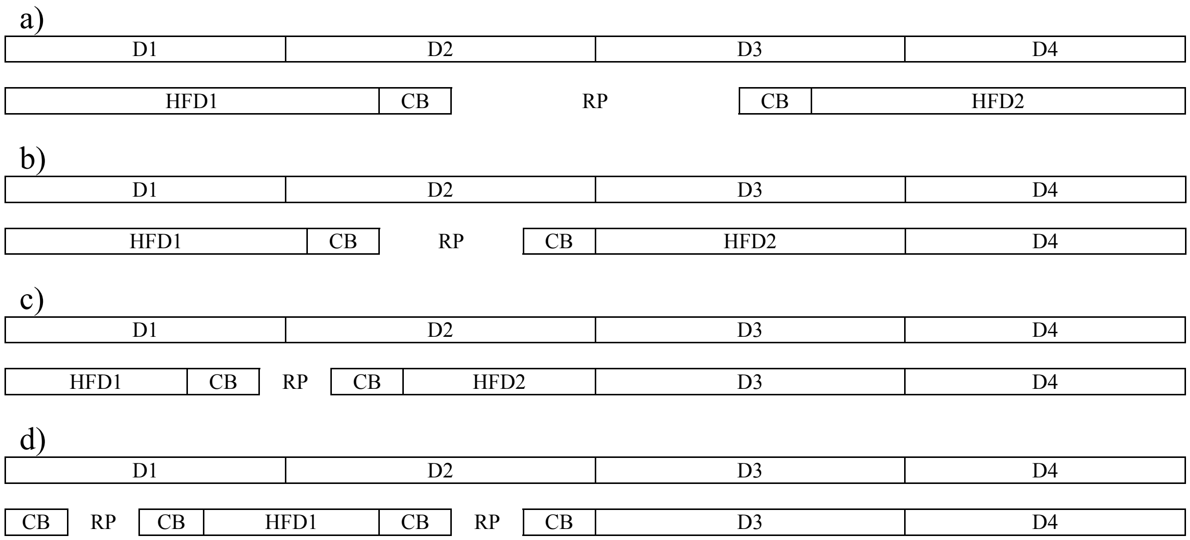

Fig. 1. Possible scenarios of half-sell modification for roman pots installation:

- D1-D4 – standard Tevatron dipoles
- HFD1-HFD2 – new strong dipoles
- CB – cryoboxes for warm bypasses

The calculated dependence of the space available for the roman pots in the Tevatron half-cell vs. the nominal field in the new dipole magnets for the above scenarios is shown in Fig. 2. The magnetic length of the new dipoles vs. their nominal field is shown in Fig. 3. The calculations are based on the Tevatron dipole parameters presented above and the following design parameters of the new magnets discussed in [1]:

- the expected length of new magnet ends including cryostat L_{end_new}=0.589 m
- the cryo-box length for the warm bypass L_{bp}=0.43685 m

Two limiting factors – the minimal space for the roman pots of ~4 m and the maximum mechanical length of new magnets limited by the A0 drop 9.119 m [1] shown by the dashed lines on the plots – restrict the minimum nominal field in the new magnets by ~6.7 T.

The maximum nominal field in the new magnets is limited by magnet cost and technology. Increasing the maximum field in the magnet increases the space for the roman pots and simultaneously decreases the magnet length which will reduce the magnet cost. However, the complexity of magnets with higher fields in this field range exceeds the benefits of the length reduction. The nominal field of 8-9 T for this particular task should be considered as a reasonable upper limit.

Taking into account the above remarks one could conclude that 2-by-1 scenario is not realistic due to very high required magnetic field, B_{nom}>15 T. Scenario 4-by-2 is more expensive than 3-by-2 scenario due to larger magnet length at practically the same B_{nom} and the same space provided for the Roman Pots.

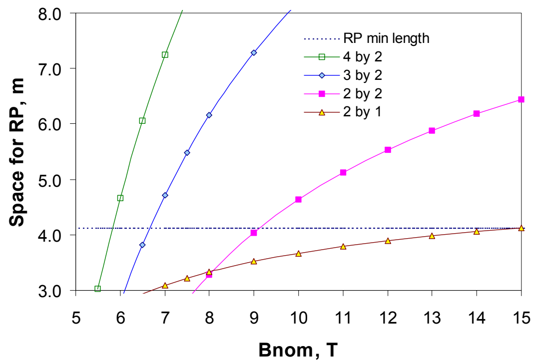

Fig. 2. The space available for roman pots in half-cell vs. the nominal field in new magnets.

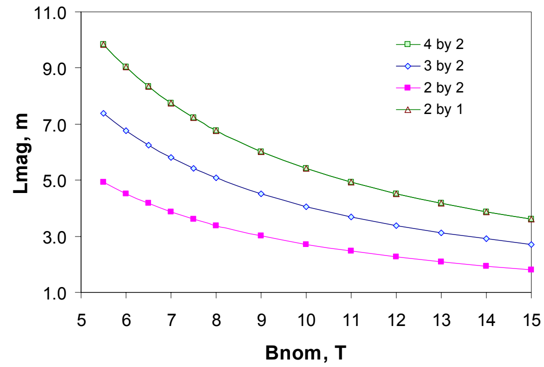

Fig. 3. The magnetic length of the new dipole vs. their nominal field.

Magnet design and technology

To be compatible with the Tevatron magnet system the new dipole magnets should have the same aperture, nominal current, and operation temperature as the Tevatron main dipoles. The examples of possible coil cross-sections of the new strong dipole magnets which meet the above requirements are shown in Fig. 4.

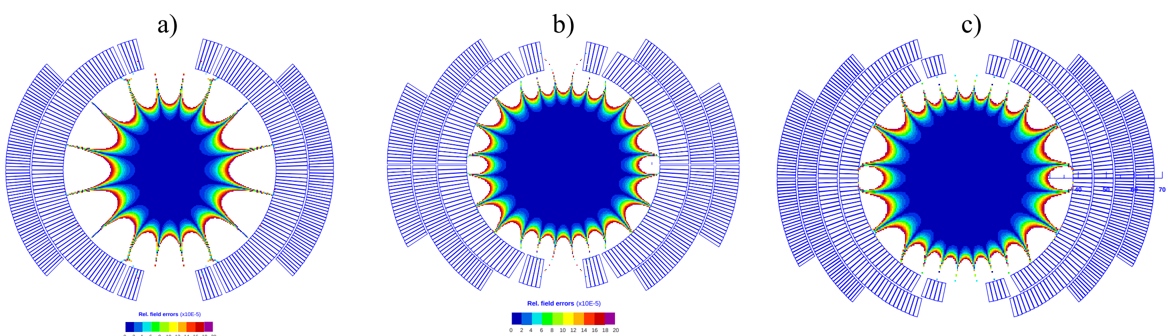

Fig. 4. Cross-sections of strong dipole magnets for the Tevatron:
a) 5.5 T two-layer design; b) 6.7 T three-layer design; c) 9 T four-layer design.

The required field level as well as the required compatibility with the Tevatron systems (cryogenic, vacuum, power, etc.) dictates to the following design solutions:

- large coil aperture of 76 mm
- 3- or 4-layer graded coils
- small strand diameter

Analysis shows that the nominal fields of 6.7-7 T with sufficient operation margin at the Tevatron operating temperature can be achieved using the traditional NbTi magnet technology. Reaching the nominal field above 7 T at 4.5 K requires magnets based on Nb3Sn superconductor.

The NbTi magnets with nominal fields B_{nom}~6-7 T are feasible. The 1-m long model of 6 T dipole based on the UNK arc dipole magnet was developed and successfully tested in 1996 at IHEP (Protvino, Russia) [2] in the framework of Fermilab-IHEP collaboration. However, the design requirements for GTeV bring these magnets to the limit of the state-of-the-art NbTi accelerator magnet technology.

The Nb_3Sn accelerator magnet technology for magnets with B_{nom}>7 T is in the early stage of development in the world. Only three 10-13 T 1-m long dipole models with 50 mm bore have been built and successfully tested worldwide in 1989-1997 [3-5]. Fermilab's SC magnet group since 1998 is working on the development of high field accelerator magnets based on Nb3Sn superconductor.

Magnet development program

Both approaches have high risks and challenges and will require an R&D phase. For NbTi magnet program the main challenge is related to the high nominal field and large aperture. For comparison, SSC dipole was designed for a nominal field of 6.6 T in the aperture of 50 mm. The Nb_3Sn magnet program is more complicate and risky due to many uncertainties related to this new technology. More expensive superconductor and more complicate technology will increase the cost. The status of this technology also will require longer and more expensive R&D phase.

Due to challenging requirements the magnet development program must consist two phases: short model R&D and full-size magnet production. To be ready for magnet installation in FY2009 the following program schedule is anticipated:

- FY2005 – development of magnet conceptual and engineering designs, start procurement of SC strands and other long-term materials
- FY2006 – fabrication and test of 1-2 short models in order to check and tune design parameters and tooling, optimize technology, engineering design of long magnets, cryostat, etc.
- FY2007-FY2008 – procurement, fabrication and test of 6-8 full-size magnets
- FY2009 – magnet installation

The time available for magnet development and fabrication favors the NbTi magnets with the nominal field of ~6.5 T. The estimated cost for the proposed program based on NbTi magnet technology is summarized in the Table 1.

Table 1. GTeV NbTi magnet development cost estimates.

	Short models (1 m)	Full-scale magnets (7 m)
Number of magnets	2	6
Tooling, k$	500	2,500
Magnets, k$	300	4,000
EDIA, k$	1,500	1,000
Total, k$	2,300	7,500

The total cost of this program with NbTi magnets is ~15 M$ (including the 30% overhead and 20% contingency) spread over 4 years with the pick of ~4-5M$ per year in FY2006-FY2007.

The program described above has to be carefully coordinated with others Fermilab's magnet R&D programs and projects such as BTeV, LARP, etc. since GTeV magnet program if approved will require sharing Fermilab's production and test facilities and human resources. Certainly, it will also benefit from the above programs, especially from BTeV, using BTeV quad cryostat (possibly some modifications will be required), magnet test stand and equipment. One of the possible solutions could be to find an external partner (company or Lab) with the appropriate experience and capabilities.

References

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